STUDY OF DEMAND PATTERNS FOR MINERAL BASED COMMODITIES IN THE "HIGH TECHNOLOGY" INDUSTRIES

Final Report

by

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EXECUTIVE SUMMARY

Purpose and Scope

In this study we were asked to identify the noncommodity elements* which could find increasing applications in the remainder of this decade and into the 1990's. Having advanced information on demand, CANMET will be better prepared to plan its technology programs in areas such as beneficiation and recovery of these elements from ores or tailings. Consideration would also be given to identifying Canadian mineral and byproduct reserves of these elements. It should be noted that this study was not focussed on supply or identification of major participants - information which should also be obtained to allow CANMET to make proper decisions on its research and development planning.

Approach

The selection of noncommodity elements to be considered and a primary assessment of emerging applications for these less common elements came from industry experts within Arthur D. Little. Technologies represented included advanced ceramics, metallurgical alloys, rare earth metals (lanthanides), precious metals, fuel cells/batteries, sensors/detectors and electronic materials, with inputs and assessment by eight industry experts in these fields. The data provided by these industry experts were supplemented by an information search of promotional articles on emerging technologies.

Findings

As a result of preliminary screening, 17 metals and the 15 rare earth metals (lanthanides) have been analyzed. The major findings are:

*Noncommodity - for this report the elements which are not highly consumed in the industrialized countries and are traded lightly. For example, copper, nickel, aluminum and zinc would be commodity elements while strontium, zirconium and osmium would be noncommodity elements.

- Three elements have emerging value potential with real growth rates between 10 to 20% per year over the next ten years:

Element(s)	Potential Use
- Gallium (as GaAs)	Semiconductors Solar cells (space applications) Present usage about 10,000 Kg*
- Lithium Metal	Aluminum alloys for aerospace applications Batteries Present usage in each application about 45,000 Kg
- Neodymium	Magnets (as metal) TV Faceplates (as oxide) Present usage is insignificant for these applications In the 1990's each application could require 1 million Kg of Nd

- Other elements that may (or may not) experience increase in demand, with an estimated 5 to 10% real growth over the next ten years. Elements that should be monitored include:

Element(s)	Potential Use
- Yttrium (and Zirconium)	Stabilized zirconia for sensors and structural ceramics Total current consumption of yttria about 170,000 Kg
- Selected separated lanthanides	Magnets Phosphors
- Germanium, Tellurium (possibly Indium)	Semiconductors, detectors, lasers Photovoltaic conversion Optical storage media Fiber Optics Present usage of Ge is about 30,000Kg Electronic uses for In and Te under 1000 Kg

*U.S. usage is given for all the elements noted.

-	Beryllium	Copper alloys for connectors About 1/3 of current usage of 300,000 Kg may experience high growth
-	Rhodium	For European automotive catalysts This application not yet established Present automotive usage is about 2000 Kg European usage could be of the same order

Recommendations

To complement this study, the worldwide supply of the elements mentioned should be analyzed as well as the current participants and their capacities. Information should also be obtained on the chemical purity of the elements required for the emerging applications. In the future, every three to five years, we recommend that a supply/demand study be performed to identify emerging applications for the noncommodity elements.

SOMMAIRE D'EXECUTION

But et champ d'activité

Dans cette étude on nous a demandé d'identifier les éléments non commerciaux(*) qui pourraient trouver de plus en plus d'applications d'ici la fin de cette décennie et dans les années 1990. Possédant des renseignements sur leur approvisionnement, CANMET pourra être à mieux de planifier des programmes technologiques dans des domaines tels que réduction et récupération de ces éléments à partir des minerais ou des résidus. On s'attachera aussi à identifier les réserves minérales et les réserves de sous-produits en ces éléments appartenant au Canada. Il faut noter que ce travail ne se limite pas seulement a l'étude de l'approvisionnement et à l'identification des principaux composants -- renseignement qui devrait aussi être obtenu pour que CANMET puisse prendre des décisions adéquates concernant son programme de recherche et développement.

Approche

Des experts industriels chez ADL ont selectionné les éléments non commerciaux à considerer et ont donné une première évaluation des applications qui en ressortent pour ces éléments peu communs. Les technologies représentées comprennent les céramiques avancées, les alliages métallurgiques, les terres rares (lanthanides), les piles combustibles/batteries, les capteurs/détecteurs et matériaux électroniques, dont les données et estimations sont tenues par huit experts industriels dans chaque domaine. Les données rapportées par ces experts ont été fournies par une recherche d'information concernant les articles promotionnels sur les technologies nouvelles.

Conclusions

Sur la base d'un tri préliminaire, 17 métaux et 15 terres rares (lanthanides) ont été analysés.

(*) Non commerciaux -- dans ce rapport ce sont les éléments qui ne sont pas grandement utilisés dans les pays industrialisés et peu échangés. Par exemple, le cuivre, le nickel, l'aluminium et le zinc seraient des éléments commerciaux alors que le strontium, le zirconium et l'osmium seraient des éléments non commerciaux.

- Trois éléments ont une valeur potentielle émergente avec des taux de croissance réelle entre 10 a 20% par an sur les dix prochaines années :

Elément(s)	Applications possibles
- Gallium (en tant que GaAs)	Semi-conducteurs Piles solaires(application spatiale) Consommation actuelle aux environs de 10.000 kg(*)
- Lithium	Alliages d'aluminium pour applications aérospatiales Batteries Consommation actuelle dans chaque branche aux environs de 45.000 kg
- Néodyme	Aimants (en tant que métal) Ecran télé (en tant qu'oxyde) La consommation actuelle pour chacune de ces applications est insignifiante Dans les années 1990, chaque application pourrait nécessiter 1 million de kg de Nd

- Les autres éléments qui peuvent (ou pas) subir une augmentation de demande, avec une croissance réelle estimée entre 5 a 10% sur les dix prochaines années.
Les éléments qui doivent être controlés comprennent:

Elément(s)	Applications possibles
- Yttrium (et Zirconium)	Zircone stabilisée pour capteurs et céramiques de construction Consommation actuelle totale d'Yttrie aux environs de 170,000 Kg
- Lanthanides choisies et séparées	Aimants Phosphores
- Germanium, Tellure (peut-etre Indium)	Semi-conducteurs, détecteurs, lasers Conversion photovoltaique Milieux de stockage optique Fibres optiques Consommation actuelle de Ge aux environs de 30.000 kg Moins de 1000 kg de In et Te pour les applications électroniques

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(*) La consommation américaine (USA) est donnée pour tous les éléments mentionnés.

- Béryllium	Alliages de cuivres pour connexions Environ 1/3 d'une consommation actuelle de 300.000 kg pourrait subir une forte croissante
- Rhodium	Pour les convertisseurs catalytique de voitures Cette application n'est pas definitive La consommation actuelle pour les voitures se situe aux alentours de 2000 Kg La consommation européenne pourrait être du même ordre de grandeur

Recommandations

Pour compléter cette étude, l'offre mondiale des éléments mentionnés doit être analysée aussi bien que leurs composants actuels et leurs qualités. Des renseignements devraient aussi être obtenus sur la pureté chimique des éléments requise par les applications nouvelles. A l'avenir, tous les trois à cinq ans, nous recommandons vivement qu'une étude sur l'offre et la demande soit faite pour déterminer les applications qui en ressortent pour les éléments non commerciaux.

I. INTRODUCTION

The Government of Canada wishes to identify those inorganic materials which will experience high growth in demand during the remainder of this decade and into the 1990's. Of particular interest is the identification of emerging or new technologies which would precipitate an increase in demand for these materials. With this information the Canadian minerals industry can become prepared with the proper recovery and refining technologies.

The focus is on identifying new or emerging technologies rather than current applications that will result in increased demands for specific noncommodity elements. However, comment on major, established growth opportunities as they now exist is useful as well.

PERIODIC TABLE OF THE ELEMENTS

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0	Orbit
1 +1 −1 H															2 0 He	K
3 +1 Li	4 +2 Be									5 +3 B	6 +2 +4 −4 C	7 +1 +2 +3 +4 +5 −1 −2 −3 N	8 −2 O	9 −1 F	10 0 Ne	K-L
11 +1 Na	12 +2 Mg									13 +3 Al	14 +2 +4 −4 Si	15 +3 +5 −3 P	16 +4 +6 −2 S	17 +1 +5 +7 −1 Cl	18 0 Ar	K-L-M
19 +1 K	20 +2 Ca	21 +3 Sc	22 +2 +3 +4 Ti	23 +2 +3 +4 +5 V	24 +2 +3 +6 Cr	25 +2 +3 +4 +7 Mn	26 +2 +3 Fe	27 +2 +3 Co	28 +2 +3 Ni	29 +1 +2 Cu	30 +2 Zn	31 +3 Ga	32 +2 +4 Ge	33 +3 +5 −3 As	34 +4 +6 −2 Se	35 +1 +5 −1 Br	36 0 Kr	L-M-N
37 +1 Rb	38 +2 Sr	39 +3 Y	40 +4 Zr	41 +3 +5 Nb	42 +6 Mo	43 +4 +6 +7 Tc	44 +3 Ru	45 +3 Rh	46 +2 +4 Pd	47 +1 Ag	48 +2 Cd	49 +3 In	50 +2 +4 Sn	51 +3 +5 −3 Sb	52 +4 +6 −2 Te	53 +1 +5 +7 −1 I	54 0 Xe	M-N-O
55 +1 Cs	56 +2 Ba	57* +3 La	72 +4 Hf	73 +5 Ta	74 +6 W	75 +4 +6 +7 Re	76 +3 +4 Os	77 +3 +4 Ir	78 +2 +4 Pt	79 +1 +3 Au	80 +1 +2 Hg	81 +1 +3 Tl	82 +2 +4 Pb	83 +3 +5 Bi	84 +2 +4 Po	85 At	86 0 Rn	N-O-P
87 +1 Fr	88 +2 Ra	89** +3 Ac	104 —+4	105 —	106													O P Q

KEY TO CHART

Atomic Number — 50 +2 — Oxidation States
Symbol — Sn +4

Transition Elements

Transition Elements

Group 8

*Lanthanides	58 +3 +4 Ce	59 +3 Pr	60 +3 Nd	61 +3 Pm	62 +2 +3 Sm	63 +2 +3 Eu	64 +3 Gd	65 +3 Tb	66 +3 Dy	67 +3 Ho	68 +3 Er	69 +3 Tm	70 +2 +3 Yb	71 +3 Lu		N O P
**Actinides	90 +4 Th	91 +3 +4 Pa	92 +3 +4 +5 +6 U	93 +3 +4 +5 +6 Np	94 +3 +4 +5 +6 Pu	95 +3 +4 +5 +6 Am	96 +3 Cm	97 +3 +4 Bk	98 +3 Cf	99 +3 Es	100 +3 Fm	101 +2 +3 Md	102 +2 +3 No	103 +3 Lr		O P Q

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II. METHODOLOGY

The elements evaluated in this study are shown on the facing page. The primary assessment on the emerging applications for the non-commodity elements came from our industrial experts. These people have many years of experience in their fields and have developed an excellent sense of the reality of new technology and the timing. Without the benefit of an expert's opinion one is faced with trying to produce order out of the numerous scientific and technological papers and articles which appear on emerging technologies. Most, if not all of these publications are one sided, advocating a technical concept or technology. Often, they are not useful in gaining an understanding of the status of an emerging technology.

Prior to obtaining the experts opinions, we performed a literature search on the elements focussing on promotional articles. This allowed us to identify possible new applications which could then be assessed by the experts. We have used this approach in the past and find it to be a better locator of new technology than the technical literature which is not applications oriented.

We were not surprised by the outcome of the literature search. The technological areas which could require new materials developments are those which place the highest demands and requirements on performance: catalysis, semiconductors, sensors/detectors, magnetics, information storage, energy conversion, batteries/fuel cells and aerospace alloys. Within these areas, the materials used will change if better performance is demonstrated.

Although experts are the best resource to assess potential applications, their information can become dated with the occurrence of new developments. For this reason, this study should only be used to indicate trends with the realization that actual demands for the elements can change in time.

As an example, the applications of neodymium to magnets has been announced in the past year and the potential demand could be significant. If this study had been performed several years ago, this application of neodymium would not have been identified. To maintain awareness on the emerging applications for the noncommodity elements, CANMET should carry out an analysis similar to this at least every three to five years. This is an adequate interval to pick up new developments in materials applications.

LANTHANIDES (INCLUDING YTTRIUM)

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1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0	Orbit
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3 +1 Li	4 +2 Be									5 +3 B	6 +2 +4 −4 C	7 +1 +2 +3 +4 +5 −1 −2 −3 N	8 −2 O	9 −1 F	10 0 Ne	K-L
11 +1 Na	12 +2 Mg									13 +3 Al	14 +2 +4 −4 Si	15 +3 +5 −3 P	16 +4 +6 −2 S	17 +1 +5 +7 −1 Cl	18 0 Ar	K-L-M
19 +1 K	20 +2 Ca	21 +3 Sc	22 +2 +3 +4 Ti	23 +2 +3 +4 +5 V	24 +2 +3 +6 Cr	25 +2 +3 +4 +7 Mn	26 +2 +3 Fe	27 +2 +3 Co	28 +2 +3 Ni	29 +1 +2 Cu	30 +2 Zn	31 +3 Ga	32 +2 +4 Ge	33 +3 +5 −3 As	34 +4 +6 −2 Se	35 +1 +5 −1 Br	36 0 Kr	K-L-M-N
37 +1 Rb	38 +2 Sr	39 +3 Y	40 +4 Zr	41 +3 +5 Nb	42 +6 Mo	43 +4 +6 +7 Tc	44 +3 Ru	45 +3 Rh	46 +2 +4 Pd	47 +1 Ag	48 +2 Cd	49 +3 In	50 +2 +4 Sn	51 +3 +5 −3 Sb	52 +4 +6 −2 Te	53 +1 +5 +7 −1 I	54 0 Xe	K-L-M-N-O
55 +1 Cs	56 +2 Ba	57* +3 La	72 +4 Hf	73 +5 Ta	74 +6 W	75 +4 +6 +7 Re	76 +3 +4 Os	77 +3 +4 Ir	78 +2 +4 Pt	79 +1 +3 Au	80 +1 +2 Hg	81 +1 +3 Tl	82 +2 +4 Pb	83 +3 +5 Bi	84 +2 +4 Po	85 At	86 0 Rn	K-L-M-N-O-P
87 +1 Fr	88 +2 Ra	89** Ac +3	104 —+4	105 —	106													K-L-M-N-O-P-Q

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**Actinides	90 +4 Th	91 +5 +4 Pa	92 +3 +4 +5 +6 U	93 +3 +4 +5 +6 Np	94 +3 +4 +5 +6 Pu	95 +3 +4 +5 +6 Am	96 +3 Cm	97 +3 +4 Bk	98 +3 Cf	99 +3 Es	100 +3 Fm	101 +2 +3 Md	102 +2 +3 No	103 +3 Lr

Orbit
N O P
O P Q

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III. LANTHANIDES (INCLUDING YTTRIUM)

The lanthanides are the "rare-earth" series of 15 consecutive elements in the Periodic Table, beginning with lanthanum and ending with lutetium. Because of its chemical similarity, yttrium is generally included in the group as well. Table III-1 shows the principal sources, with the relative abundances of the individual lanthanides. Almost all the rare-earth ore processed is either bastnaesite (U.S. or Chinese) or monazite (Australian, Indian, Brazilian, or Malaysian). These ores are very low in the less-used "heavy" rare earths (Tb, Dy, Ho, Er, Tm, Yb, and Lu), but xenotime (Malaysian) can supply these "heavies" as a byproduct of yttrium manufacture. The total industry volume worldwide is about 32,000 metric tons of rare-earth oxides; capacity is almost twice this much.

The lanthanides find application either as mixtures or as separated elements. We outline below the major trends in uses of the lanthanides and the implications for Canada's deposits.

A. RARE-EARTH MIXTURES

After cerium is separated from the mixtures, about 25% of the remaining rare earths are used for mischmetal production by chloride electrolysis. Mischmetal is used principally as an addition agent to steel and ductile cast iron for control of inclusions, and therefore its use depends upon the volume of steel output. This is not a growth area.

About 45% of the total rare earths are used as chloride mixtures in catalyst formulations for the petroleum and petrochemicals industry. This use also has not been growing. However, there is a trend to put more cerium (which is presently in oversupply) into these formulations.

Table III-1. Composition of Rare-Earth Ores
(percent of total rare-earth content)

Element	Oxide	Bastnaesite		Monazite		Xenotime
		California	Bayan Obo	Rhone-Poulenc*	Australia	Malaysia
Cerium	CeO_2	50.0	50	46.5	45.5	5.0
Lanthanum	La_2O_3	32.5	27	23.0	23.0	.5
Praseodymium	Pr_6O_{11}	4.2	5	5.1	5.0	.7
Neodymium	Nd_2O_3	12.0	15	18.4	18.0	2.2
Samarium	Sm_2O_3	.8	1.1	2.6	3.5	1.9
Europium	Eu_2O_3	.11	.23	.07	.1	.2
Gadolinium	Gd_2O_3	.15	.4	1.7	1.8	4.0
Terbium	Tb_4O_7		.05	.16		1.0
Dysprosium	Dy_2O_3	.12		.52		8.7
Holmium	Ho_2O_3			.09		2.1
Erbium	Er_2O_3		NA	.13	1.0	5.4
Thulium	Tm_2O_3			.013		.9
Ytterbium	Yb_2O_3	.015		.06		6.2
Lutetium	Lu_2O_3			.006		.4
Yttrium	Y_2O_3	.1	.25	2.0	2.1	60.8

* Weighted average of Rhone-Poulenc raw materials.
Sources: USBM, Rhone-Poulenc, Molycorp, Chinese Ministry of Foreign Trade

B. SEPARATED RARE EARTHS (IN ORDER OF ATOMIC NUMBER)

1. Lanthanum

Most lanthanum is sold mixed with other rare earths (see above), but there is a small but growing use for lanthanum in high-temperature superalloys, in electro-optic displays, and in hydrogen-storage alloys (with nickel). The chief value of lanthanum is in the chloride catalyst formulations many of which are actually enriched in lanthanum. The metal is also used as a reductant in producing samarium metal.

2. Cerium

The chief use for separated cerium oxide is as a glass polishing compound; its next most important use is as a decolorizing agent in glass. These uses are declining, presently at some 20% of the total rare-earth oxide weight. As mentioned above, higher percentages of cerium are being used in rare-earth catalyst mixtures.

3. Praseodymium

We estimate that less than half of the praseodymium oxide is separated and sold, and this mainly as a yellow pigment for ceramic tile (especially popular in Europe). Uses for separated oxide are now growing. If a shortage of neodymium should develop (see below), the metal could also be in demand as a substitute for neodymium.

4. Neodymium

Until this past year, the only significant use for separated neodymium oxide was as a component of neodymium-doped glass for yttrium-aluminum-garnet lasers. Some catalyst formulations also favored enrichment of the rare-earth mixture in neodymium. Two major developments have

greatly increased the potential demand for separated neodymium--high-intensity magnetic Nd-Fe-B alloys for use in, say, automobile motors, and the development of an Nd-doped glass for increased brightness in TV-tube-faceplate use. (GE already markets it under the name Neo-Max.) These new uses could well create a shortage of neodymium and require expansion of the entire lanthanide industry. (To some extent, the neodymium shortage could be relieved by increased diversion of praseodymium from its present uses, since it behaves similarly to neodymium in the magnetic alloys.) The magnetic application of Nd appears fairly certain and will require 500-1000 metric tons Nd, depending upon specific applications. The commercial acceptance of the TV faceplate application is more uncertain. Complete penetration of the industry could require 1000 metric tons or more.

5. Promethium

This element does not occur in nature, as its longest-lived isotope (Pm-145) has a half-life of only 18 years.

6. Samarium

The chief use for separated samarium metal is as an alloying agent with cobalt in high-intensity magnets (biggest use in stereo headphones). Well over half of the samarium is being separated at present. The development of the Nd-Fe-B alloys (see above) may displace some Sm-Co magnets, but probably not for a long time.

7. Europium

This was the first of the rare earths to find a market large enough to warrant construction of a plant (20 years ago) to separate it from the others. The oxide was found to be an excellent activator for the ortho-vanadate red phosphors in TV tubes. It is still separated for this purpose, both at the ore-treatment mills and from mischmetal

electrolytic slag. Today, almost all available europium is being separated.

Demand for europium grows slowly but could increase significantly if polyphosphor fluorescent lamps become popular. These use red, blue, and green phosphors to create a "white" light just as is done with dots on a color TV screen, with an energy savings over conventional fluorescent tubes.

8. Gadolinium

This material has been used in nuclear reactors, in control rods, and as a burnable poison in fuel rods. High-purity separated gadolinium is finding rapidly increased use in magneto-optic disk storage and in bubble memories, in both of which it is used in thin films with cobalt. It is also used in gadolinium-iron garnets for microwave control. Because of the demand for samarium, with which it is associated, more gadolinium is being separated than is being sold.

9. "Heavies" (Terbium through Lutetium)

These relatively rare materials have found only very small-volume uses. Terbium is sometimes used with gadolinium in magneto-optic films and as an activator for some green phosphors, and erbium is sometimes used as a glass colorant. All of them are in oversupply.

C. YTTRIUM

Yttrium oxide has been used for some time for garnet materials in laser and microwave applications. It also finds uses in phosphors. A new use, growing rapidly, is as a stabilizing agent for high-temperature applications of cubic zirconia. This material is used for oxygen sensors and has potential for use in the internals of high-performance engines. The rising demand for yttrium has already begun to push up the price of its principal source (xenotime, see Table III-1), and, of course, to make for an even greater oversupply of the "heavies."

Present consumption of yttrium oxide is at a rate of about 170 metric tons.

D. MAJOR PARTICIPANTS

The major producers are Molycorp, Rhone-Poulenc, and W.R. Grace. Molycorp, a division of Union Oil, has extensive bastnaesite reserves at Mountain Pass, California, and until now, has been the world's leading supplier of ore; it has the ability to separate Ce, La, Pr, Nd, Sm, Eu, Gd, and Y, but does not separate the "heavies." Rhone-Poulenc purchases monazite, primarily from Australia and India, and separates all the rare earths in Texas and in France. W.R. Grace purchases monazite and makes a mix of Ce-La-Pr-Nd for its catalyst sales, selling off the rest of its rare earths as mixed concentrates.

In addition, Research Chemicals (Phoenix) and MCI-Megon (Norway) make the heavies and yttrium, in high purity, from xenotime. There are also close to a dozen small Japanese producers. Major producers of mischmetal are Ronson and Remacor (U.S.), and Treibacher (Austria). Goldschmidt (Germany) produces intermetallics, such as the Sm-Co alloys, through its co-reduction process.

A new entry into the picture is Mainland China, which has bastnaesite reserves many times larger than those of any other country. They have begun selling concentrates (and rare-earth chlorides to mischmetal producers) in competition with established suppliers, and have, from their publications, been developing an extensive capability for separation of individual rare earths by the usual solvent-extraction technology.

E. FACTORS OF INTEREST TO CANADA

Monazite is generally found in connection with thorium oxide, which must usually be separated prior to shipment of the ore. If any of the Canadian ores are associated with this oxide, an allowance should be

made for the potential value of the thorium to the CANDU nuclear program as a future "converter" source of U-233 fuel.

If the Canadian ores are very extensive or are particularly rich in Nd, Pr, Eu, or Y, this would make them especially attractive. We understand that the Strange Lake occurrence contains gadolinite, which would be comparatively rich in yttrium, for example.

If the deposits are simply conventional bastnaesite or monazite, with none of the above "pluses," there would be little incentive to develop them in competition with existing suppliers.

ELECTRONIC MATERIAL ELEMENTS

PERIODIC TABLE OF THE ELEMENTS

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0	Orbit
1 +1 −1 H															2 0 He	K
3 +1 Li	4 +2 Be									5 +3 B	6 +2 +4 −4 C	7 +1 +2 +3 +4 +5 −1 −2 −3 N	8 −2 O	9 −1 F	10 0 Ne	
11 +1 Na	12 +2 Mg									13 +3 Al	14 +2 +4 −4 Si	15 +3 +5 −3 P	16 +4 +6 −2 S	17 +1 +5 +7 −1 Cl	18 0 Ar	K-L
19 +1 K	20 +2 Ca	21 +3 Sc	22 +2 +3 +4 Ti	23 +2 +3 +4 +5 V	24 +2 +3 +6 Cr	25 +2 +3 +4 +7 Mn	26 +2 +3 Fe	27 +2 +3 Co	28 +2 +3 Ni	29 +1 +2 Cu	30 +2 Zn	31 +3 Ga	32 +2 +4 Ge	33 +3 +5 −3 As	34 +4 +6 −2 Se	35 +1 +5 −1 Br	36 0 Kr	K-L-M
37 +1 Rb	38 +2 Sr	39 +3 Y	40 +4 Zr	41 +3 +5 Nb	42 +6 Mo	43 +4 +6 +7 Tc	44 +3 Ru	45 +3 Rh	46 +2 +4 Pd	47 +1 Ag	48 +2 Cd	49 +3 In	50 +2 +4 Sn	51 +3 +5 −3 Sb	52 +4 +6 −2 Te	53 +1 +5 +7 −1 I	54 0 Xe	L-M-N
55 +1 Cs	56 +2 Ba	57* +3 La	72 +4 Hf	73 +5 Ta	74 +6 W	75 +4 +6 +7 Re	76 +3 +4 Os	77 +3 +4 Ir	78 +2 +4 Pt	79 +1 +3 Au	80 +1 +2 Hg	81 +1 +3 Tl	82 +2 +4 Pb	83 +3 +5 Bi	84 +2 +4 Po	85 At	86 0 Rn	M-N-O
87 +1 Fr	88 +2 Ra	89** +3 Ac	104 —+4	105 —	106													N-O-P
																		O P Q

Transition Elements

Transition Elements

Group 8

KEY TO CHART

Atomic Number → 50 +2 ← Oxidation States
Symbol → Sn +4

*Lanthanides	58 +3 +4 Ce	59 +3 Pr	60 +3 Nd	61 +3 Pm	62 +2 +3 Sm	63 +2 +3 Eu	64 +3 Gd	65 +3 Tb	66 +3 Dy	67 +3 Ho	68 +3 Er	69 +3 Tm	70 +2 +3 Yb	71 +3 Lu	N O P
**Actinides	90 +4 Th	91 +5 +4 Pa	92 +3 +4 +5 +6 U	93 +3 +4 +5 +6 Np	94 +3 +4 +5 +6 Pu	95 +3 +4 +5 +6 Am	96 +3 Cm	97 +3 +4 Bk	98 +3 Cf	99 +3 Es	100 +3 Fm	101 +2 +3 Md	102 +2 +3 No	103 +3 Lr	O P Q

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IV. ELECTRONIC MATERIALS

Several of the Group III, IV, V and VI elements have been gaining prominence for use in electronic materials. Applications include semiconductors, lasers, optical fibers, displays, sensors and detectors, optical storage media and photovoltaics. These electronic applications fall in three categories with respect to uses of these elements.

- Major use of element (>95%): Ga, Ge. U.S. markets for these elements in high purity form (99.999%) are about U.S. $6 million (Ga) and U.S. $30 million (Ge). World demand may be twice these levels.

- Moderate use of element (10-30%): In, Se, Te. Demand for high-purity elements is low, representing U.S. $0.1-0.2 million markets in the U.S. Lower grade compositions and compounds have flat or decreasing markets because of substitution and other factors. Therefore, the unit value for electronic grades may drop if demand for electronic grades increases substantially.

- Minor use of element (1% or less): As, Sb. These elements and their compounds represent approximately U.S. $50 million a year markets in the U.S. and up to U.S. $200 million worldwide. However, requirements for electronic grades are low, representing U.S. $0.2-1 million markets. Mineral byproduct and secondary sources of these elements are substantial. Increased demand and higher purity requirements for electronic grade arsenic could represent a significant increase in unit value. However, the current market of about U.S. $1 million is low.

Applications for these elements and market trends are given in Table IV-1.

Table IV-1. Summary Market Data for Certain Elements used in the Electronics Industry

Market Statistic ($ US)	Element						
	Ga	Ge	In	Se	Te	As	Sb
World Production (1000 Kg)	25	38	NA	1200	150	27,000	55,000
US Consumption (1000 Kg)	10	26	20	600	45	16,000	12,000
Cost ($/Kg)	630	1020	115	7-8	26-30	1-5	3-5
Cost-electronic grade ($/Kg)	630	1060	NA	NA	NA	100	NA
Market size ($MM)							
Electronic - US	6	30	<0.2	<1	0.2	0.2	<0.2
Total US	6	30	20	5	2	40	50
World	15	50	NA	10	6	60	200
Use (%)							
Electronic, electrical	90	95	40	35	10	<1	<1
Ferrous, nonferrous alloys	--	--	50	--	75	3	60
Glass and ceramics	--	--	--	30	--	5	20
Chemical industry	--	--	--	25	15	90	20
R&D	10	5	--	--	--	--	--
Other	--	--	10	10	--	1	--

Source: Minerals Yearbook
Arthur D. Little, Inc. Estimates

A. GALLIUM

Electronic applications of gallium are almost entirely as GaAs, GaAℓAs and GaP compounds. Principal applications include light-emitting diodes (LED's), solar cells (especially for space, applications) and diode lasers. In the early 1960's, GaAs was referred to as the electronic material of the future. However, only very recently has the technology of growing defect-free, high-purity, single-crystal ingots of GaAs developed sufficiently to permit the commercial production of GaAs integrated circuits (IC's).

In our opinion, use of GaAs for integrated circuit devices represents a major market with a probable real growth rate of 20% per year. GaAs has the advantage of faster switching, lower power requirements and greater thermal tolerance than silicon, and the Japanese have indicated their plans to exploit these features for fifth-generation computers. Some drawbacks, such as the need to apply dialectric coatings (silicon can be oxidized to SiO_2 by heating in a controlled atmosphere) and improved metallization techniques, should not detract significantly. Published estimates of gallium demand do not, in our opinion, take into account the maturity of GaAs research and the commercialization potential of the IC market. With reference to Figure IV-1, we estimate a U.S. $50-60 million market (U.S. $1983) for high-purity gallium by the end of the century. This is consistent with capturing about 10% of the silicon IC market, where base material is expected to reach market values of U.S. $500 million by the mid-1990's.

In addition to electronic device applications, there is a tremendous potential for gallium demand in photovoltaic energy conversion. If U.S.policy supports a major dependence on solar energy sources, GaAs solar cells will play a major role. The characteristics of GaAs make it the prime candidate for space applications, including

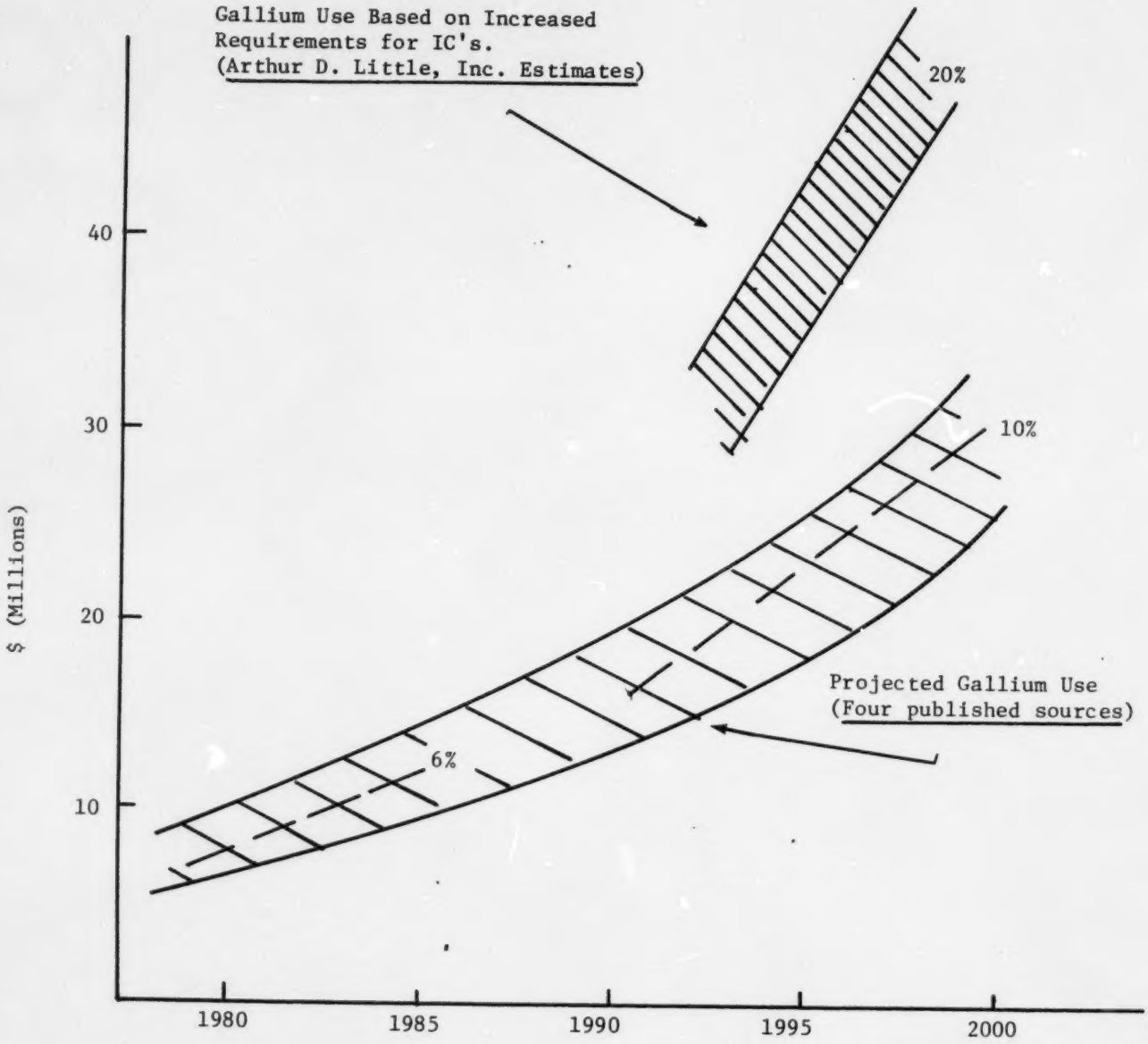

Figure IV-1. Estimated Demand for Electronic Grade Gallium Metal

military uses. A thermal insensitivity, relative to silicon, makes GaAs concentrator collectors for solar energy attractive. We believe that the probability for significant GaAs-based solar cell development prior to the end of the century is low (5-10%). A reversal in current U.S. government position, however, could increase demand by 2 to 3 orders of magnitude by the end of the century. Technical advancements in this area and trends in U.S. government policy should be followed carefully.

B. GERMANIUM

Germanium is consumed solely by the electronics industry, in applications that involve infrared optics (45%), optical fibers for communication (20%), semiconductors (15%), detectors (10%) and miscellaneous uses. Military markets are growing substantially, but long-range growth in this area will be influenced by the dominating political party in the United States.

Germanium is produced by several U.S. refiners as a zinc smelting byproduct. Scrap services 30-40% of the supply. Reserves are widely distributed. Growth in demand could be up to about 5 to 10% for the next decade depending mainly upon the growth rate of optical fibers for communication.

C. INDIUM

Indium is obtained from zinc smelter fume recovery. Annual consumption has been declining slightly. Applications are in low-melting-point alloys and solders (40%), electrical components (40%), conductive glass coatings (5%) and research and development (15%). InP is a semiconductor which may have some increased interest for use in solar cells.

D. SELENIUM

Demand for selenium, which is presently in oversupply, has increased very slightly, with the greatest use in xerography processes (35-40%), largely offsetting reduced use in rectifiers. Other uses are in glass making (30%) and various applications by the chemical industry (25-30%). Seienium, as is tellurium, is a byproduct of anode slimes from electrolytic refining of copper, with secondary supplies from xerography wastes and rectifier scrap. After substantial reductions in the late 1970's and early 1980's prices have now stabilized and modest increases are expected. No major opportunities or new application areas have been identified.

E. TELLURIUM

In addition to being recovered from copper slimes, some tellurium and selenium are obtained as byproducts from silver and gold refining. As a result of significant reductions in use for free-machining steels (40% of applications) due to both substitution by bismuth and the reduced demand for steel in the early 1980's, tellurium is also in oversupply. Other applications for tellurium are in non-ferrous alloys (20%), cast iron additions (15%), rubber compounding (15%), and electronics (10%). Although electronic applications are relatively modest, there is currently a significant increase in demand for high-quality Hg-Cd-Te infrared detectors by the military. Moreover, the requirement for very high purities adds considerably to value. Another application that has recently been commercialized and has taken on growing significance is use in erasable optical storage media. Doped tellurium oxide films undergo a phase transformation with laser illumination that increases optical reflectivity. The films are very thin, however, and the quantity of tellurium required for this application may be quite small.

F. ARSENIC

Substantial amounts of arsenic are utilized, with 97% in compound form, mainly as As_2O_3. Most of the compounds are used in the chemical and agricultural industries (90%), with smaller amounts in glass making (5%) and other applications. Three percent in the metallic form is used in alloying. Approximately 10,000 Kg of electronic grade arsenic, with a value of about $100/Kg, is used in preparing GaAs and related compounds for use in LED's, lasers, microwave applications, integrated circuits and solar cells. This requirement will grow in parallel with gallium demands that were given earlier. As sources of As are plentiful, the major future requirement for As will be increased high purity refining capacity. As demands increase, GaAs scrap and other processing wastes may be refined for arsenic content, thereby reducing the demand for primary arsenic. At present, however, GaAs scrap is refined only for gallium content.

G. ANTIMONY

Antimony, produced from primary and secondary sources, has been in oversupply. The Lake George, New Brunswick, mine has been closed since 1981. Applications have been in alloying (mainly with lead to increase hardness), flameproofing, ceramics and glasses, chemical and rubber processing and type metal. No major electronic applications have been developed or are likely to develop in the near future. However, InSb is used for detectors but the markets are small.

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0	Orbit
1 +1 −1 H		KEY TO CHART: Atomic Number → 50 +2 Sn +4 ← Oxidation States; Symbol →								5 +3 B	6 +2 +4 −4 C	7 +1 +2 +3 +4 +5 −1 −2 −3 N	8 −2 O	9 −1 F	2 0 He 10 0 Ne	K K-L
3 +1 Li	4 +2 Be									13 +3 Al	14 +2 +4 −4 Si	15 +3 +5 −3 P	16 +4 +6 −2 S	17 +1 +5 +7 −1 Cl	18 0 Ar	K-L-M
11 +1 Na	12 +2 Mg	Transition Elements						Transition Elements								
							Group 8									
19 +1 K	20 +2 Ca	21 +3 Sc	22 +2 +3 +4 Ti	23 +2 +3 +4 +5 V	24 +2 +3 +6 Cr	25 +2 +3 +4 +7 Mn	26 +2 +3 Fe	27 +2 +3 Co	28 +2 +3 Ni	29 +1 +2 Cu	30 +2 Zn	31 +3 Ga	32 +2 +4 Ge	33 +3 +5 −3 As	34 +4 +6 −2 Se	35 +1 +5 −1 Br	36 0 Kr	-L-M-N
37 +1 Rb	38 +2 Sr	39 +3 Y	40 +4 Zr	41 +3 +5 Nb	42 +6 Mo	43 +4 +6 +7 Tc	44 +3 Ru	45 +3 Rh	46 +2 +4 Pd	47 +1 Ag	48 +2 Cd	49 +3 In	50 +2 +4 Sn	51 +3 +5 −3 Sb	52 +4 +6 −2 Te	53 +1 +5 +7 −1 I	54 0 Xe	-M-N-O
55 +1 Cs	56 +2 Ba	57* +3 La	72 +4 Hf	73 +5 Ta	74 +6 W	75 +4 +6 +7 Re	76 +3 +4 Os	77 +3 +4 Ir	78 +2 +4 Pt	79 +1 +3 Au	80 +1 +2 Hg	81 +1 +3 Tl	82 +2 +4 Pb	83 +3 +5 Bi	84 +2 +4 Po	85 At	86 0 Rn	-N-O-P
87 +1 Fr	88 +2 Ra	89** +3 Ac	104 —+4	105 —	106													O P Q

*Lanthanides	58 +3 +4 Ce	59 +3 Pr	60 +3 Nd	61 +3 Pm	62 +2 +3 Sm	63 +2 +3 Eu	64 +3 Gd	65 +3 Tb	66 +3 Dy	67 +3 Ho	68 +3 Er	69 +3 Tm	70 +2 +3 Yb	71 +3 Lu		N O P
**Actinides	90 +4 Th	91 +5 +4 Pa	92 +3 +4 +5 +6 U	93 +3 +4 +5 +6 Np	94 +3 +4 +5 +6 Pu	95 +3 +4 +5 +6 Am	96 +3 Cm	97 +3 +4 Bk	98 +3 Cf	99 +3 Es	100 +3 Fm	101 +2 +3 Md	102 +2 +3 No	103 +3 Lr		O P Q

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V. MINOR PLATINUM GROUP METALS

The minor platinum group metals (PGM) consist of rhodium, ruthenium, iridium and osmium. Of these, rhodium has the brightest outlook because of the increasing demand for it in automotive catalysts. Demand for the other minor platinum group metals probably will continue to increase gradually, but we know of no emerging applications that would create a significant opportunity for a Canadian source.

A. RHODIUM

Traditionally, rhodium has been employed in conjunction with platinum in the catalyst used for nitric acid production. Platinum-rhodium alloys also are used to line glass furnaces and in the form of spinnerets for production of glass fibers. Additionally, rhodium plating is used on instruments, sliding electrical contacts and other applications where a hard surface is required. More recently, rhodium has been used as a reducing catalyst to minimize the nitrogen oxides in automotive exhaust emissions.

Since the platinum group metal deposits in South Africa contain 3 to 7% rhodium, automotive design engineers are attempting to limit the rhodium content of whatever catalysts they develop to the natural ratio in South African ore, although the availability of rhodium from the Soviet Union has permitted some flexibility. Other known sources are of little help with respect to the future availability of rhodium. Inco's platinum group metals contain about 4% rhodium, while the Stillwater deposit in Montana contains only 1%. Thus, these sources do not offer any opportunity to alleviate a long-term shortage of rhodium. In fact, if the Stillwater deposit is exploited an even greater incentive will be created to reduce the amount of rhodium employed.

Potentially offsetting these factors is the likely long-term demand for platinum automotive oxidation catalysts in Europe. Since smog is

not a severe problem in Europe, nitrogen oxide levels probably will not be legislated. The resulting substantial demand for platinum as an automotive catalyst, with no attendant requirement for rhodium, should make rhodium more available for the North American automotive industry.

We believe it is not a question of if, but rather when, Europe will adopt pollution control standards that will require the use of platinum catalysts. Since Europe tends to be more rational than the United States where the environment is concerned, and is short of petroleum reforming (octane improvement) capacity, leaded gasoline probably will continue to be permitted. This will slow the conversion to unleaded gasoline and the use of platinum automotive catalysts.

In the long term the automotive industry requirements for rhodium as well as platinum and palladium will be met increasingly by reprocessing spent automotive catalysts. In theory, most of the North America automotive requirements for these materials ultimately could be satisfied by reprocessing spent catalyst. However, to reach this stage requires considerable time because an increasing number of vehicles are lasting 15 to 20 years. Nevertheless, the net requirements for platinum and palladium already have peaked, assuming that the automobile producers are successful in developing the expected improved catalyst and the prices of platinum and palladium are high enough to ensure recovery. Even without considering reprocessed catalyst, the demand for rhodium in this application peaked in 1983 at about 2800 Kg and is expected to fall to about 60% of this consumption by 1990. The potential supply of rhodium from recycled catalysts will not significantly affect the net demand for rhodium during this decade because rhodium was introduced into automotive catalysts effectively only in 1981 model-year vehicles.

Obviously, a relatively high rhodium-content PGM ore would be desirable under the present set of circumstances. Indeed, since rhodium traditionally has demanded the highest price of all the PGM's, usually selling for about twice the price of platinum, a

high-rhodium-content ore has always been of interest. In recent months rhodium has received considerable speculative interest because the price of rhodium was well below this traditional relationship.

B. RUTHENIUM

The principal uses for ruthenium are as a resistor material for integrated circuits, in platinum-ruthenium alloy electrical contacts, and in the form of a ruthenium oxide coating on titanium anodes used in the chloralkali industry. Ruthenium is in relatively plentiful supply. In South African ores 8 to 11% of the PGM content is ruthenium, making it about twice as plentiful as rhodium. However, selling at U.S. $45 per ounce, ruthenium not only is the lowest-cost PGM, but also is the only one of these elements that costs less than it did 25 years ago. In contrast, since the late 1950's the prices of both platinum and palladium have increased sevenfold. We know of no reason to expect a significant opportunity in ruthenium to develop in the foreseeable future.

C. IRIDIUM

The principal use for iridium is as a laboratory crucible material, where it is particularly important in the production of semiconductor materials for the electronics industry. Iridium also is alloyed with platinum for use as petroleum reforming catalyst and as a hardener for jewelry. In the United States, consumption of iridium in recent years has been about 600 Kg.

The consumption of iridium is expected to grow as a result of the continuing increase in the demand for semiconductors. However, we know of no significant emerging applications that would promise to provide any opportunities for a new producer of iridium.

D. OSMIUM

Osmium accounts for about 1% of the PGM content of South African ores, about one-half the iridium content. However, the market for osmium is a small fraction of the estimated 2000 Kg of osmium mined each year. For example, the United States consumes only about 30 Kg per year.

Most of the osmium is alloyed with platinum and ruthenium (60% osmium, a few percent ruthenium, balance platinum), in which form it is extremely resistant to abrasive wear. Such alloys are used to make fountain pen nibs, electrical contacts and instrument pivots. We know of no emerging applications for osmium that would justify further consideration.

PERIODIC TABLE OF THE ELEMENTS

Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIII	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	0	Orbit
1 +1 −1 H															2 0 He	K
3 +1 Li	4 +2 Be									5 +3 B	6 +2 +4 −4 C	7 +1 +2 +3 +4 +5 −1 −2 −3 N	8 −2 O	9 −1 F	10 0 Ne	K-L
11 +1 Na	12 +2 Mg	Transition Elements							Transition Elements	13 +3 Al	14 +2 +4 −4 Si	15 +3 +5 −3 P	16 +4 +6 −2 S	17 +1 +5 +7 −1 Cl	18 0 Ar	K-L-M
19 +1 K	20 +2 Ca	21 +3 Sc	22 +2 +3 +4 Ti	23 +2 +3 +4 +5 V	24 +2 +3 +6 Cr	25 +2 +3 +4 +7 Mn	26 +2 +3 Fe	27 +2 +3 Co	28 +2 +3 Ni	29 +1 +2 Cu	30 +2 Zn	31 +3 Ga	32 +2 +4 Ge	33 +3 +5 −3 As	34 +4 +6 −2 Se	35 +1 +5 −1 Br	36 0 Kr	-L-M-N
37 +1 Rb	38 +2 Sr	39 +3 Y	40 +4 Zr	41 +3 +5 Nb	42 +6 Mo	43 +4 +6 +7 Tc	44 +3 Ru	45 +3 Rh	46 +2 +4 Pd	47 +1 Ag	48 +2 Cd	49 +3 In	50 −2 +4 Sn	51 +3 +5 −3 Sb	52 +4 +6 −2 Te	53 +1 +5 +7 −1 I	54 0 Xe	-M-N-O
55 +1 Cs	56 +2 Ba	57* +3 La	72 +4 Hf	73 +5 Ta	74 +6 W	75 +4 +6 +7 Re	76 +3 +4 Os	77 +3 +4 Ir	78 +2 +4 Pt	79 +1 +3 Au	80 +1 +2 Hg	81 +1 +3 Tl	82 +2 +4 Pb	83 +3 +5 Bi	84 +2 +4 Po	85 At	86 0 Rn	-N-O-P
87 +1 Fr	88 +2 Ra	89** +3 Ac	104 —+4	105 —	106													O P Q

*Lanthanides	58 +3 +4 Ce	59 +3 Pr	60 +3 Nd	61 +3 Pm	62 +2 +3 Sm	63 +2 +3 Eu	64 +3 Gd	65 +3 Tb	66 +3 Dy	67 +3 Ho	68 +3 Er	69 +3 Tm	70 +2 +3 Yb	71 +3 Lu		N O P
**Actinides	90 +4 Th	91 +5 +4 Pa	92 +3 +4 +5 +6 U	93 +3 +4 +5 +6 Np	94 +3 +4 +5 +6 Pu	95 +3 +4 +5 +6 Am	96 +3 Cm	97 +3 +4 Bk	98 +3 Cf	99 +3 Es	100 +3 Fm	101 +2 +3 Md	102 +2 +3 No	103 +3 Lr		O P Q

Key to chart: Atomic Number → 50 +2 +4 ← Oxidation States; Symbol → Sn

Group 8

Arthur D. Little, Inc.

VI. OTHER METALS

A. BERYLLIUM

Increased demands for beryllium metal in the late 1970's and early 1980's, principally for defense applications, are now diminishing as these defense applications have been satisfied. Use in Cu-2% Be alloys, however, is growing in parallel with growth of the electronics industry. Demand is met in the U.S. by bertrandite ores in Utah and imports of beryl. Alloying accounts for major consumption, with use in connectors, sockets, springs and bearings for the electronics, automotive and aircraft industries, as well as the military. Some BeO is utilized in specialty glass and ceramics products. Together these represent a market of about U.S. $50 million.

The relatively high growth rate of 15-20% for specialty Cu-2% Be alloys, representing one-third of the consumption of beryllium, makes this metal sufficiently interesting to warrant future monitoring, especially if military applications and requirements increase. It should be emphasized that this opportunity is based on increasing demand for established uses rather than on emerging technology.

B. LITHIUM

The United States is the primary producer and user of lithium. Foote Mineral Co. and Lithco share about equally in the production of lithium and lithium compounds from spodumene ores in North Carolina and subsurface brines in Nevada. Over half of the world's reserves are in Chile and 20% in the United States. A limited partnership between one of the U.S. producers and a Chilian national company is expected to come on line in 1984, adding significantly to capacity.

Approximately one-third of the estimated 2000 metric tons of contained lithium consumed annually is used as lithium carbonate in aluminum potlines. Demand in 1982 and early 1983 dropped because of the depressed state of the aluminum industry but has now recovered. Other

continuing uses of lithium (representing 40% of consumption) are in glass and ceramics manufacturing and lubricants . These markets, however, are being influenced by substitutions, such as plastic beverage containers for glass. This substitution is largely offset by increased use in some specialty and TV glasses.

Two technologies are emerging that will increase demand significantly: aluminum-lithium alloys and lithium batteries. Aluminum - 3 weight percent lithium alloys exhibit lower density and higher stiffness and elastic modulus than comparable aluminum alloys, such as 7075, although ductility is somewhat lower. The lower density makes aluminum-lithium alloy air frames very attractive to the aerospace industry because of the resulting fuel economies. Research has been carried out on two forms of alloy production: powders followed by consolidation, and ingot. The U.S. Air Force, the principal supporter of research, and the industry appear now to favor the ingot approach and Alcoa is constructing a U.S. $50 million dedicated casting facility which will go on line in late 1985. Conservatively, this facility will have an annual production rate of 5 million Kg (corresponding to a demand for 140 metric tons lithium, or about 7% of total current consumption of contained lithium). Midline estimates between the most optimistic and conservative scenarios for aluminum-lithium alloy requirements reach 650 metric tons lithium by 1993. After 6 years at this level, the market will decline because of lithium recovery from scrap alloy and the increased use of lightweight composites. Other transportation markets, such as rail and transit system vehicles, may offset some or all of this decline.

Industry participants in this technology include, in addition to Alcoa, Martin-Marietta, Alcan and probably Reynolds and Kaiser.

Lithium batteries have been in development for 20 years and are now being commercially exploited in several marketplaces. The market is distributed among commercial (70%), industrial (20%), and military/-aerospace (10%) applications, ranging in unit U.S. cost from $0.50-$3.00 for commercial uses to $3.00-$15.00 for military applications.

The market is split about evenly between replacement and new applications. In fact, several products are being designed around the use of lithium batteries for powering, based on high energy density and long shelf life. A typical example is power for electronic circuit protection. The most optimistic estimates for lithium growth in batteries indicate an-order-of magnitude increase in market within 5 years from a current U.S. consumption of 50 metric tons annually. Other estimates of lithium demand for this application indicate growth rates in consumption of 15-20% for the next decade.

Potentially, a very significant demand for lithium is represented by electric storage batteries for use in the automotive and power generation industries. This market is not expected to become significant until the year 2000. Moderate application of lithium to the storage battery area could compensate for decreased lithium demand by the end of the century due to declining markets (i.e., for Al-Li alloys) and scrap recovery. Developments in this area should be followed.

C. SCANDIUM

Scandium is a byproduct of uranium and tungsten ores. Since supply far exceeds demand, little of the available scandium is recovered. Annual world demand is in the range of 30 Kg, representing a value of about U.S. $300,000. About one-third is used in electrical components and the rest for alloying, ceramics and research purposes. Scandium-target x-ray tubes represent the only recent new application. With the relatively high cost of recovery, ample reserves and lack of specialty applications, we see no reason to expect increased usage in the near future.

D. STRONTIUM

Strontium ores are imported, mainly from Mexico, for an annual demand of about 15,000 metric tons of contained strontium. Principal requirements are for strontium compounds, mainly as carbonate and nitrate representing an annual domestic market of about U.S. $10

million. The major use (65%) is in TV face plates, which use strontium glass to eliminate secondary x-ray emission. Other uses are in pyrotechnics (15%), ferrite ceramic permanent magnets (10%) and miscellaneous specialty uses. Considerable mineral reserves are distributed around the world. Demand is expected to be flat into the 1990's. No significant new technologies are emerging that will influence demand for strontium in the near future.

E. RHENIUM

Rhenium, which is recovered as a byproduct from the processing of molybdenite concentrates derived from low-grade porphyry copper deposits, is a relatively newly discovered element, having been first isolated in 1925.

The principal use for rhenium, accounting for about 90% of the total U.S. demand for this element, is in the form of a platinum-rhenium catalyst for petroleum reforming. This "bimetallic" catalyst has replaced most of the platinum "monometallic" catalyst, which was in use up to the mid-1970's. The advantages of the platinum-rhenium bimetallic catalyst is that it can tolerate more carbon build-up and is more efficient than the monometallic catalyst since it can operate at a higher temperature and lower pressure.

Various rhenium alloys, principally with tungsten, molybdenum, nickel, platinum and palladium, account for about 10% of the rhenium demand in the United States. These alloys are used in a variety of electronic and instrumentation applications.

The outlook for rhenium, like platinum, is tied to the adoption of automotive catalytic converters in Europe. Before catalytic converters can be adopted, the lead in gasoline will have to be reduced. We do not expect use of lead to be eliminated in Europe because to do so would require construction of so much new petroleum reforming capacity. Assuming the ultimate balance calls for a significant reduction in, but not complete elimination of, the lead

content, the demand for rhenium for bimetallic refinery catalysts will increase.